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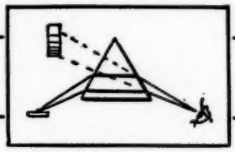

JUNE
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Journal of the
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VOLUME 24 JUNE, 1934 NUMBER 6

Rayleigh's Law of Scattering in the Infrared*

A. H. PFUND, *The Johns Hopkins University*

(Received May 5, 1934)

The scattering is inferred from transmission measurements carried out on transparent particles of zinc oxide and other finely divided crystals. Rayleigh's law of scattering is obeyed for the smallest particles of 0.088μ diameter but not for larger particles. Conclusions as to particle size and size distribution are drawn from the transmission curves. The effect of varying the refractive index of the medium surrounding the particles on the transmission curves is found to be in accord, qualitatively, with Rayleigh's formula.

IN the deduction of Rayleigh's law of scattering it was assumed that the transparent scattering particles had diameters which were small in comparison with the wave-length of the incident radiation. If experiments seeking to test the above law be carried out in the visible or ultraviolet regions, the necessary particle-size becomes so minute that accurate measurement of this quantity becomes difficult—to say nothing of the possibility of procuring particles of nearly constant size. By extending the observations into the infrared, however, the great increase in wave-length makes possible the use of coarser particles whose diameters may be determined with considerable accuracy.

In a sense, the work to be presented is largely of a qualitative nature. This is necessarily so because there is no supply of particles whose diameters lie within very narrow limits. Again, the refractive indices of the materials used are not known in the infrared. In spite of this it was thought that the results obtained were sufficiently interesting to warrant a brief presentation.

Since the particles dealt with were essentially transparent in the visible and infrared, it was found more convenient to measure changes in the intensity of transmitted radiation—it being tacitly assumed that radiations not transmitted were lost by scattering. Tests of Rayleigh's law were carried out on zinc oxide which had been dispersed[1] in crepe rubber by milling. Subsequently the mass was dissolved in xylene and diluted with nujol. Dispersions produced in this manner are essentially perfect. When studied under "dark-field" illumination, these dispersions yield measurements of particle-size (by the "count" method) of striking reproducibility.[2] To illustrate this point a number of determinations[3]

* Presented at the New York Meeting of the Optical Society, Feb. 24, 1934.

[1] Gehman and Morris, Ind. and Eng. Chem. Anal. Ed., p. 157, April, 1932.

[2] Gamble and Pfund, J.O.S.A. **23**, 416 (1933).

[3] Prepared by Mr. Clyde Hall of the Research Laboratory of the New Jersey Zinc Company.

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for several samples of fine zinc oxide are given. For each determination the cell in which the counts were made was filled with fresh material:

Sample I	*Sample II*	*Sample III*
0.200	0.146	0.338
0.201	0.146	0.341
0.203	0.145	0.344
0.203	0.145	0.342

Since rubber and all suspension media become opaque in the infrared near 3μ it was attempted to produce dry films of highly dispersed particles containing no medium other than air. This was accomplished by mulling a pigment (zinc oxide, titanium dioxide, basic sulphate white lead, etc.) with butyl alcohol for about three minutes so as to break up aggregates as thoroughly as possible. The paste was then placed on a large plate of polished rocksalt and was spread out into a thin, uniform layer by means of a piece of plate glass about 8×8 cm attached to the muller with soft wax. Dry films of the finer pigments such as TiO_2 or ZnO showed a deep ruby-red color in transmitted light. Another type of film containing a minimum amount of binder was prepared by spreading the butyl-alcohol-pigment paste on a large piece of plate glass on which an area of constant film-thickness was isolated. When the film was dry, a dilute solution of nitrocellulose in amyl alcohol was flowed over the chosen area and the film was allowed to dry. Subsequently, it was immersed in water so as to make it let go of the glass. The wet film was then mounted over an opening cut in a flat metal plate.

Most of the work was carried out by means of a thermocouple and a small glass monochromator whose range extended from 0.4μ to about 2.7μ. For regions of greater wave-length, the usual rocksalt spectrometer and vacuum thermocouple were employed.

The first point taken up was to determine the relation between particle-size and wave-length at which the transition from non-selective reflection to selective scattering set in. For this purpose some basic carbonate of white-lead having a particle-diameter of 0.8 microns was spread on a glass plate in a layer one particle deep and with large, clear spaces between particles. The transmission curve is shown in curve *A*, Fig. 1. Here it is evident that the transmission and, hence, the

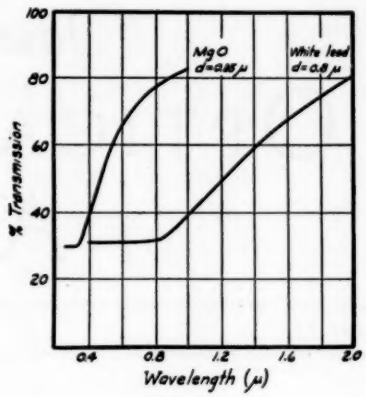

FIG. 1.

reflection, is non-selective about up to the point at which particle-size and wave-length are equal. An increase in wave-length results in selective scattering. Similar conclusions were reached by studying the ultraviolet transmission of a similar thin film of MgO of 0.35μ particle diameter on a quartz plate. In curve *B*, Fig. 1, it is again shown that the transmission is non-selective up to the point at which wave-length and particle size are equal.

Next, the transmission curves of zinc-oxides dispersed in rubber were measured to determine the degree to which these curves followed Rayleigh's law. The particle-sizes of the various dispersions, previously determined[4] elsewhere by the count-method, were found to be 0.088μ, 0.11, 0.15, 0.22, 0.395. The pigment concentration in all samples was constant and had the value 0.01177 g pigment per cc of suspension. The thickness of layer was 1.52 mm. The curves shown in Fig. 2 are of the ratios of transmission through the dispersion to the transmission through an equal layer of the clear rubber-xylene vehicle. The complete Rayleigh formula[5] for the transmission of radiation through a scattering medium is:

$$I=I_0\exp\left[4\pi^2(n^2-n_0^2)^2/(n^2+2n_0^2)^2NV^2/\lambda^4\right], \quad (1)$$

[4] I am indebted to Mr. C. Hall for these careful measurements.

[5] Wien-Harms Handbuch d. Exptl. Physik **19**, 368, (Gans).

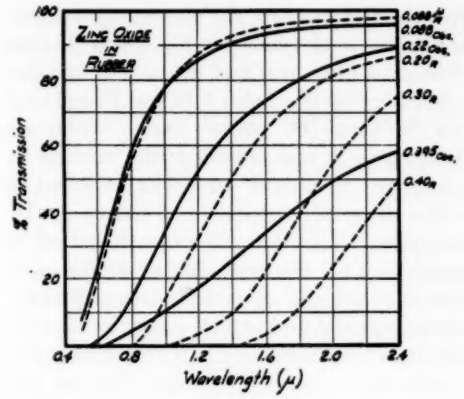

FIG. 2.

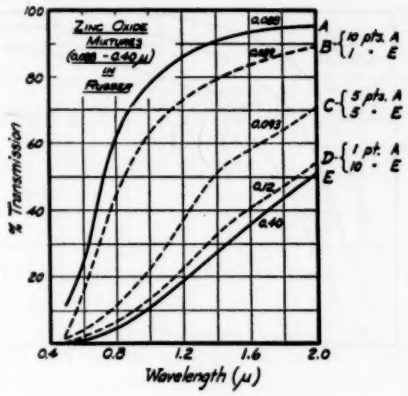

FIG. 3.

where

I = intensity of transmitted radiation,
I_0 = intensity of incident radiation,
n = refractive index of pigment particle,
n_0 = refractive index of medium,
N = number of particles per cc,
V = volume of particle,
d = diameter of equivalent spherical particle,
λ = wave-length.

Since the pigment-concentration in all dispersions is the same, the mass of pigment (m) per cc of suspension will be $NV\rho$, where ρ is the density of the pigment. Assuming the terms involving refractive indices to be constant, and considering the volume V as proportional to d^3, the exponent in Eq. (1) takes on the simplified form:

$$Kd^3/\lambda^4. \qquad (2)$$

On this basis, Rayleigh curves R (dotted) for particles having diameters 0.088μ, 0.2, 0.3, 0.4 were calculated, the value of K being found from the observed transmission at $\lambda = 1\mu$. While the agreement between calculated and observed curves is moderately good for the smallest particles ($d = 0.088\mu$) the disparity becomes increasingly greater as the particle-size becomes larger. This points to a lack of uniformity of particle-size. Even though an experimental curve follows a Rayleigh curve closely, it is not permissible to draw the conclusion that all particles are of the same size within narrow limits. It simply means that in case of nonuniformity the summation of the NV^2 terms in expression (1) may be replaced by some average value and that the dependence of the transmission upon $1/\lambda^4$ is the same as if the particle size were constant *provided* that all wave-lengths be so large that even the largest particles in the complex have diameters which are small in comparison to the shortest wave-lengths. Clearly, then, the disparity between the calculated and observed curves for particles of 0.4μ diameter is to be attributed to the fact that in the suspension there were many particles so large as to render Rayleigh's law inapplicable within the range of wave-lengths used.

In Fig. 3 the transmission curves for known mixtures of the finest (0.088μ) and the coarsest (0.395μ) suspensions are presented. Following the usual methods employed in evaluating particle sizes by the "count method," the average particle sizes for the mixtures were calculated. The curves show that the average particle size of the mixture containing 10 parts of coarse to 1 part of the fine suspension has increased only to 0.12μ while the transmission curve is only slightly different from that applying to coarsest particles ($d = 0.395\mu$). This simply means that while the count method favors the small particles, the transmission curves favor the large ones. It would seem then that by imposing upon a pigment the two conditions (1) that the (count) particle-size have a given value and (2) that the transmission curve be of a definite form, the pigment will be specified more closely than on the basis of particle-size alone.

If a pigment-film of uniform thickness be laid down, the resultant transmission curve will vary

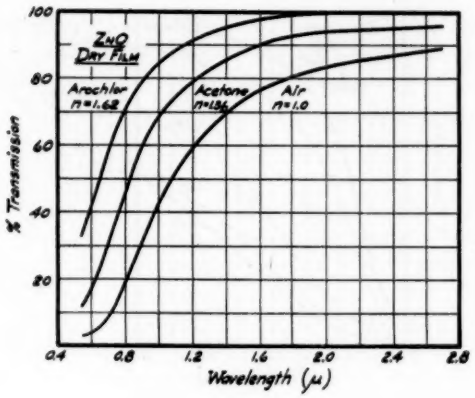

FIG. 4.

with the nature of the medium surrounding the particles. In fact, according to Eq. (1) the effective particle diameter (d) may be considered as being equal to the sixth root of the expression: $((n^2-n_0^2)/(n^2+2n_0^2))^2 \cdot d^6$, where V^2 has been replaced by d^6. Accordingly, then, a decrease in the refractive index difference between pigment and medium ought to result in a Rayleigh curve for a pigment of smaller d. That this is true is shown by the results of the following experiment:

Some ZnO of small but unknown particle size was mulled with butyl alcohol—the resultant paste being spread out into a uniform film according to the procedure already outlined. When the film was dry, the transmission curve A (for pigment alone) shown in Fig. 4 was obtained. A thin glass plate was laid in the film and some acetone of refractive index 1.36 was flowed in the space between the plates—under which conditions curve B was obtained; the acetone was allowed to evaporate and was replaced by arochlor of refractive index 1.62 (curve C). It is noted that, since the refractive index of the pigment is 2.01, the replacing of air by media which reduced the refractive index difference between pigment and vehicle gave rise to curves which could be simulated by dry films containing particles of reduced diameter. Having once established by trial the "best" particle-size to yield maximum hiding-power when refractive index of pigment and medium are known, it is merely necessary to re-establish this curve in order to obtain the best particle-size of any other pigment in any vehicle.

Because of the fact that conclusions as to lack of uniformity of particle size are drawn from the short wave-length portions of a transmission where Rayleigh's law is inapplicable, it is evident that, for the present, the transmission curves cannot be translated into "particle-size distribution curves." In spite of this, the transmission curves retain their usefulness in giving decisive information as to the manner in which pigments differ, i.e., whether in particle-size or distribution.

Spectral Distribution of Radiation from High and Low Pressure Hg Arcs

B. T. BARNES, *Incandescent Lamp Department, General Electric Company*

(Received May 4, 1934)

JOHNSON and Burns[1] have published data on the energy radiated in certain strong lines and in four broad regions of the spectrum from low and high pressure Hg arcs. Benford[2] has given data on the ultraviolet portion of the spectrum from a high pressure arc. McAlister[3] has determined the intensities of the infrared lines of wave-lengths between 1 and 2μ from a similar arc. Taken together, these three sets of data give a fairly complete picture of the spectrum of a high pressure Hg arc. However, on account of differences in operating conditions and probably appreciable differences between the arc tubes used, such data are not strictly comparable. The present article gives the intensities of all the ultraviolet, visible and infrared lines easily measurable with a single spectro-radiometric outfit.

Our data were taken on Uviarc and Cooper Hewitt tubes of the types designed for horizontal operation with 110 to 120 v direct-current line voltage and on a vertical Uviarc designed for operation on a 220 v direct-current line. They were run at approximately the average currents in ordinary use. No reflectors were used with the tubes. However, the cathode end of each Uviarc was wrapped with asbestos to make the Hg vapor pressure the same as in normal operation in a reflector. The Cooper Hewitt tubes were not wrapped at all.

The line intensity measurements were made with our quartz double monochromator.[4] A thermopile, calibrated with Bureau of Standards radiation standards, was used for measuring all of the stronger and most of the weaker lines from the high pressure arcs. Additional data on the high pressure and most of the intensities for the low pressure arcs were obtained with Na and Cs photoelectric tubes calibrated by comparison with the thermopile. A Uviarc was used as source for these calibrations.

The exit slit of the monochromator was always set wider than the entrance slit. This allowed groups of close lines, such as at λλ3021–27 and λλ3650–63A, to be measured with a single setting. For most of the measurements, the entrance slit was 0.8 and the exit 1.2 mm wide. With these slits the band which is completely transmitted is 3.3A wide at 2313A, 8.5 at 3000, 55 at 5500 and 208A wide at 12,500A. It then decreases and is only 120A wide at 26,000A. The entire range of wave-lengths totally or partially transmitted is five times as great, i.e., 16.5A at 2313A and 1040A at 12,500A.

The low pressure tubes were inclined 5° from horizontal. The tube axis was perpendicular to the collimator axis and intersected the latter at a distance of 136.3 cm from the slit. A diaphragm mounted in front of the tube allowed radiation from a length of 23.2 cm of the arc near the center of the tube to enter the monochromator. The results were reduced to terms of intensity per meter tube length at two meters distance by assuming the positive column to be uniform and using the inverse square law. The 110 v high pressure arc tube was inclined about 5° from horizontal and its axis was 70.8 cm from the slit. The 220 v tube was operated vertical at a distance of 121 cm from the slit. Radiation from the entire tube was allowed to enter the monochromator in the case of the high pressure arcs. No condensing lens was used in any of the measurements.

The data obtained on low pressure arcs are given in Table I. The red and infrared lines were too weak to be measured except for the one at λ10140A.

Table II gives radiation intensity data for two high pressure arcs. It should be noted that in this table the density of the energy flux from the

[1] Johnson and Burns, J.O.S.A. **23**, 55 (1933).
[2] Benford, J. Motion Picture Eng. **14**, 404 (1930).
[3] McAlister, Phys. Rev. **34**, 1142 (1929).
[4] Forsythe and Barnes, Rev. Sci. Inst. **4**, 289 (1933).

TABLE I. *Intensity of radiation from low pressure mercury vapor tubes ($\mu w/cm^2$ per meter of arc length at two meters distance from axis of tube).*

Tube	Inside diameter	Arc* length	Tube voltage	Current	λ10140	5770 −91	5461	4358 −39	4047 −78†	3650 −63	3341	3126 −32	3021 −27	2967A
Lead glass	2.4 cm	128 cm	71.9	3.70 Amp.	7.0	5.2	15.9	16.2	11.5	5.7	0.51	2.6	0.054	0.019
Uviol	2.45	132	73.4	3.70	6.3	5.0	15.1	15.1	9.9	4.2	.36	2.9	.21	.39
Corex D	2.5	130	72.2	3.70	6.0	5.1	15.8	16.1	11.2	5.6	.55	5.4	.48	1.02
Quartz	2.4	58	39.7	3.70		4.8	15.0	15.2	11.0	5.4	.54	6.1	.65	1.75

Tube	λ2925	2894	2800 −07	2753	2697 −701	2652 −55	2576	2535 −39	2482 −84
Uviol	0.009	0.07	0.006	0.006	0.000	0.003	0.000	0.01	0.00
Corex D	.025	.23	.029	.041	.003	.040	.002	.53	.00
Quartz	.047	.45	.100	.205	.023	.54	.07	26.	.08

Tube	λ2464	2447	2399 2401 −80	2378	2353 −54	2323	2302 −04	2259 −61A
Quartz	0.02	0.01	0.02	0.03	0.01	0.005	0.01	0.01

* Anode to edge of cathode chamber.

† Includes only two-thirds of the line at λ4078A.

TABLE II. *Intensity of radiation from high pressure mercury vapor tubes ($\mu w/cm^2$ at two meters distance from axis of tube).*

Type	Inside diameter	Arc length	Tube voltage	Current	λ16900 17100	15300	13570 −955†	11890 −2130	11187 −290	10140	7606 −729	7082* −92
220 v	1.5 cm	16.2 cm	174 v	3.75 Amp.	8.4	2.1	10.8	4.1	7.3	20.6	0.6	1.5
110	1.5	8.5	75	3.75	2.9	.9	3.2	.9	2.3	5.4		.2

Type	λ6716	6234	5770 −91	5461	4916	4358 −39	4047 −78**	3902 −06	3650 −63	3341	3126 −32	3021 −27	2967	2925	2894
220 v	0.8	0.6	60	49	1.3	43.4	24.5	1.3	75	6.3	49	25.5	13.0	2.1	5.2
110		.15	18.3	16.6	.5	14.5	8.5	.4	26	1.9	17.7	7.8	3.9	.5	1.4

Type	λ2800 −07	2753	2697 −701	2652 −55	2576	2535 −39	2482 −84	2464	2447	2399 −401	2378 −80	2353 −54	2323	2302 −04	2259 −61
220 v	10.4	3.4	4.8	21	8	25	9	1.5	1.2	4.0	4.0	2.8	1.7	2.5	1.8
110	2.7	.9	1.2	5.8	1.0	8	2.3	.4	.3	1.0	.9	.5	.3	.5	.3

† Only half of line at 13,955A included.

* Includes about half of line at 6907A.

** Includes only two-thirds of line at 4078A.

entire arc is given, whereas in Table I the energy flux density per meter arc length is recorded.

The continuous spectrum from the anode of the 110 v high pressure arc has its maximum at about λ12000A with an intensity of 0.09 $\mu w/cm^2$ per 50A at two meters distance. With the 220 v arc, the maximum appeared to be at 11,000A and the intensity nearly 0.30 $\mu w/cm^2$ per 50A at two meters distance. However, the radiation in weak Hg lines included with the anode radiation doubtless raised and distorted the continuous spectrum curve appreciably. If one were particularly interested in measuring anode radiation it could of course be done more satisfactorily if most of the arc radiation were eliminated by the use of suitable diaphragms.

It should be pointed out that the data in this paper were obtained on only one tube of each type. Even in the spectral regions where the arc tube absorbs a negligible portion of the radiation another tube might give line intensities differing by as much as 10 percent from those obtained with the particular tubes measured. Where the absorption is high, as in the extreme ultraviolet portion of the measurable spectrum, intensities obtained with different tubes might not even be of the same order of magnitude.

The reliability of our data was tested by comparing check readings, by recalibrating our instruments and by measuring with the same monochromator the visible radiation from directional candlepower standards calibrated by the Bureau of Standards. The probable error of the data in Tables I and II is estimated to range from about 5 percent for the strongest lines to perhaps 50 percent for the weakest lines. The closeness of agreement between check readings is roughly indicated by the number of significant figures used in recording each intensity value in Tables I and II.

A Study of the Errors in the Photographic Method of Comparing Light Intensities

J. TRACY LAY AND I. CLYDE CORNOG, *Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pennsylvania*

(Received March 2, 1934)

The chief sources of error in the photographic method of comparing light intensities of the same wave-length are the variations in density over the plate caused by its irregular structure and its uneven development. The causes and magnitudes of these errors are studied by exposing plates to a field of illumination the degree of whose uniformity of intensity is measured with a photo-cell and amplifier. The main objections and difficulties ordinarily associated with the photographic method are briefly discussed, and methods are suggested for their control and correction.

INTRODUCTION

THE use of the photographic method in comparing small differences in intensity of a given line in the helium spectrum,[1] caused by small changes in the accelerating potential, has led the authors to an investigation of the errors introduced by density variations arising from the nature of the photographic plate itself and from its development. Numerous papers[2] have been published concerning the variations in density over a photographic plate which has been exposed to a field of radiation of "uniform" intensity, and many methods have been suggested for reducing these variations, but much of this work seems to be of doubtful reliability due to the fact that the degree of uniformity of the light field was not measured. Modern photo-cell technique, however, makes possible the investigation of the degree of uniformity of a light field, and the authors have recently published a full description[3] of a method and the apparatus used for securing a field of illumination uniform to 0.3 percent, and of the light intensity meter used in measuring relative light intensities in such a case.

The appended bibliography contains references to the literature dealing with photographic theory and practice,[4] and with photographic photometry.[5]

METHODS AND RESULTS

Eighty-one "Eastman 40" plates 8×10 inches in size, comprising plates of two different emulsion numbers, were exposed through a mask having apertures an inch square near each of the corners of the plate and an aperture of approximately three inches square in the middle. These plates were exposed in a light field of constant spectral distribution. The degree of uniformity of the intensity of the field was measured for all exposures.

A pendulum shutter giving a constant time of exposure was used in making all exposures. This constant time of exposure served to obtain characteristic curves which were plotted from the densities obtained from numerous areas exposed to light fields of various intensities using suitable masks, and such curves were plotted from time to time to make sure that the density readings were

[1] I. Clyde Cornog, *A Study of the Energy Relations in the Helium Spectrum*, Phys. Rev. **32**, 746 (1928).

[2] André Callier, *Some Experiments in Photographic Research Work*, Phot. J. No. 53, 242 (1913); Olaf Block, *The Uniform Development of Dry Plates*, Phot. J. No. 61, 425 (1921); W. Clark, *Standard Development*, Phot. J. No. 69, 76 Feb. (1925).

[3] J. Tracy Lay and I. Clyde Cornog, *A Light Beam of Uniform Intensity of Cross Section*, R. S. I. **4**, 600 (1933).

[4] C. B. Neblette, *Photography; Its Principles and Practice*, D. Van Nostrand, 1931. This treatise contains a very extensive bibliography of theoretical, experimental and practical photography.

[5] George R. Harrison, *Instruments and Methods used for Measuring Spectral Light Intensities by Photography*, J. O. S. A. and R. S. I. **19**, 267 (1929). This paper presents a summary of photographic photometry, and includes an extensive bibliography.

obtained on the "straight line" portion of the characteristic curve for the plates and development used. In addition, the approximate value of the contrast γ was obtained for each plate by making an additional exposure on the unexposed part of each plate.

Three microphotometer readings 1 mm apart were made near the centers of each of the exposed squares and three readings for the adjacent unexposed plate at a sufficient distance from the edge of the square to avoid edge effects. The average of the three readings for each of these positions was used to calculate the plate densities at these points.

All plates were developed in the dark by time-temperature development and the temperature of the developer was maintained at 20°C by a water bath. Sufficient developer was mixed to develop all the plates in a group and fresh and equal portions of the developer were used for each plate.

The results obtained in this research are shown in the appended table of results, Fig. 2.

The relation between a density D and the deflection of the galvanometer δ of the microphotometer is

$$D=\log(\delta_m/\delta), \tag{1}$$

in which δ_m is the galvanometer deflection for the direct light beam, i.e., for a density equal to zero.

The density of the exposed area of a photographic plate obtained with a microphotometer is the total density D of that area, comprising the density due to the glass D_g, gelatine constituent of the emulsion D_e, exposure to radiation to be measured Δ, exposure to extraneous radiation D_s, and development fog D_f. The total density may be expressed according to Eq. (2).

$$D=\Delta+D_g+D_e+D_s+D_f. \tag{2}$$

The sum of the four last densities in Eq. (2) are assumed to comprise the density of the background of the plate (D_b), hence

$$\Delta=D-D_b. \tag{3}$$

The quantity Δ in Eq. (3) will hereafter be called the "exposure density." It is the variation in this "exposure density" caused by irregularities of the plate structure and uneven development which is the subject of this investigation.

It should be mentioned that this "exposure density" will be subject to some error due to the fact that the background correction must necessarily be obtained from a different point on the plate and it will also probably differ in magnitude from the density which would be caused solely by exposure to the light source, since the added density from fog or stray light cannot be assumed equal to the corresponding density produced by these sources in the plate background, as shown by Sheppard and Mees,[6] Nietz[7] and others.

The sources of the variations in exposure density may be conveniently divided as follows:

1. Plate structure: (a) the glass or supporting film; (b) the gelatine of the emulsion; (c) heterogeneity of the emulsion; (d) the dye in color sensitive plates.
2. Exposure to extraneous radiation, such as scattered light in the spectrometer.
3. Development: (a) uneven action of the developer; (b) uneven fixing of the plate; (c) improper washing; (d) improper methods of drying.
4. Neglect in properly cleaning the glass surface of the negative before measuring the density.

1. Variations in density caused by the plate structure

(*a*) *The glass.* The average thickness of the glass was 0.152 cm with a maximum variation in average thickness of ±8.5 percent. The average optical density found for the glass was 0.048 ±0.005 with a maximum variation over a single plate of about ±0.007. The average deviation from the mean density over each plate was (0.003±0.002). This gives a most probable average percentage deviation of ±0.5 percent which the glass would cause for the exposure density Δ of 0.620.

The general character of the variations in density from point to point over the glass are shown by curve (*C*) Fig. 1. The densities from which this curve was plotted were measured directly under the points on the plate at which the values for the exposure densities of curve (*A*) were measured. This was accomplished by marking the plate with a diamond and stripping

[6] Sheppard and Mees, *Investigations on the Theory of the Photographic Process*, Longmans and Co. 1907.

[7] A. H. Nietz, *The Theory of Development*, p. 141. D. Van Nostrand, 1922.

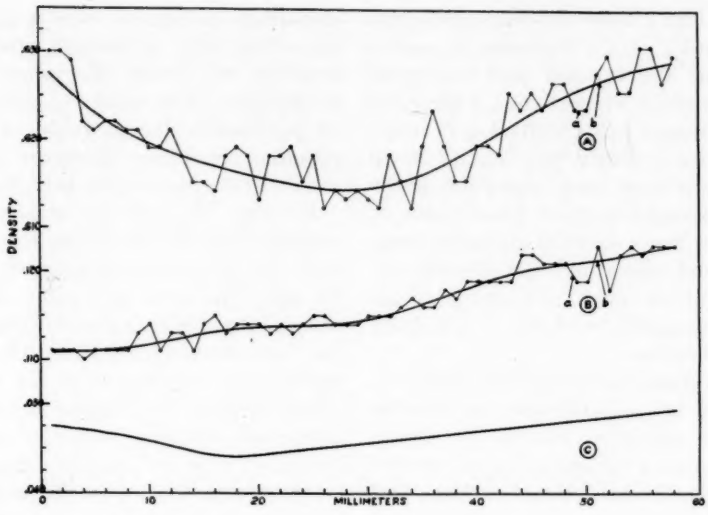

FIG. 1.

the film. It can readily be seen that the variation in density of curve $A(b)$ Fig. 1 would be reduced by correcting them by means of the variations for the clear glass shown in curve C.

(*b*) *The gelatine.* The average thickness of the emulsion after the plates were dry was found to be about 0.001 cm. The increase in the average density found for undeveloped hypo-cleared plates above the average density of the glass, in each case using the same plate stripped, was approximately 0.02. The variation in the undeveloped hypo-cleared plate was almost the same as that for the clear glass as given above, and hence had about the same probable percentage variation.

(*c*) *The heterogeneity of the emulsion.* The deviation from the average local plate density due to this cause is shown by the jagged curve $A(a)$ Fig. 1. The average deviation from the mean for this curve is ± 0.002 or ± 0.3 percent of the total average exposure density 0.620, which would approximately represent the average of variations in density from this cause in the average of three density readings taken 1 mm apart. The maximum deviation shown by this curve is about ± 1.0 percent of the average exposure density. Mees[8] shows curves illustrating this variation of density caused by the "graininess of materials" for different types of emulsions. This variation is relatively small for the fine grained emulsions found in process plates and large for the coarse grained emulsions typical of fast plates, such as the "Eastman 40" plates used by us in this research.

2. Variations in density caused by exposure to extraneous radiation

The possible errors caused by the dye in color sensitized plates and by exposure to extraneous radiation need not be discussed in this paper, since the plates investigated were not color sensitized and were so exposed that extraneous radiations were absent. Scattered light in a spectrograph, however, may introduce errors into the photographic method especially when the plate is subjected to previous and subsequent exposure to such light.[9]

3. Variations in density caused by development

(*a*) *Uneven action of the developer.* The reduction of the photoactive silver salts by development in a photographic emulsion is a chemical reaction, and in general does not proceed uniformly throughout the emulsion. The smooth curves

[8] C. E. Kenneth Mees, *Photographic Plates for Use in Spectroscopy and Astronomy*, J. O. S. A. **21**, 763 (1931).

[9] J. Tracy Lay and I. Clyde Cornog, *A Spectrograph Plate Shield*, R. S. I. **2**, 293 (1931).

$A(b)$ and $B(b)$, Fig. 1, show the character of this variation in density over a plate due to uneven development for the exposed and unexposed portions of the plate, respectively. Unless the best technique known is maintained in development the variation in density over a plate due to this fact alone will cause very large errors in the use of the photographic method. Many methods of procedure and many forms of apparatus have been devised and advocated by different investigators to attain more uniformity of development, and generally much benefit is claimed to result from their use.

The developer should fulfill three requirements. First, it should act as uniformly as possible throughout the emulsion; second, it should produce a minimum of fog; and third, it must not stain the negative. Rodinal, Metol or Elon, and combinations of the last two with hydroquinone, are generally recommended to insure these results.

Rodinal and "M. Q. 100" developers only were used in this investigation. The latter developer contains no hydroquinon, and Elon was used as the developing agent in place of Metol. The developing agent in Rodinal is paramidophenol-hydrochloride while Metol and Elon are monomethyl-paramidophenol-sulphate. Nietz[8] on page 142 gives a table of fogging velocities for different developing agents under the above-stated chemical names, in which he shows that this latter developing agent will generally produce over twice as much fog as the former. The fog densities shown in column 14, Fig. 2, for the groups of *b*, *d*, *h* and *h'* developed with Elon when compared with the fog densities of similarly developed plates using Rodinal show that the fog produced by Elon is about three times as great as that produced by Rodinal, which agrees essentially with the results of Nietz.

A comparison of the percentage density variations in columns 18, 20, 21, and 22 of the table, Fig. 2, indicate that with Rodinal developer "Brush Development" gives but little better results than those obtained with a properly rocked tray, that soaking plates in distilled water an hour before development was of no especial advantage, and that the addition of a large quantity of "bromide" to Rodinal developer does not substantially change the magnitude of the variations in density over a plate, while disadvantageously prolonging the development required to obtain the same plate density. Backing the plates seemed to have but little effect on the results, due no doubt to the method of exposing the plates. However in most photometric work this practice is highly desirable.

(*b*) *Fog.* The average density of the undeveloped hypo-cleared plates was approximately 0.07. The approximate fog density was calculated by using this value as roughly representing the average fog-free background density. These fog densities are shown in column 14, Fig. 2, and the approximate percentage of fog relative to the "exposure density" is shown in column 17 of the same table. If these values of relative fog are compared with the corresponding values of the percentage deviation from the mean found for the "exposure densities," shown in columns 18, 20, and 21 of the table, it is quite evident that the variations of density, and consequently the errors in the photographic method, increase materially with the increase of development fog.

In the table of results, Fig. 2, the variations in density shown in columns 18, 20, and 21 are abnormally high for the groups *b*, *d*, *h* and *h'*, developed with "M. Q. 100" developer, for group *f* in which a very weak developer was used, and for group *j* in which the backing was not removed before development. The remaining 51 plates show similar variations of density over their surface when compared group by group. The exposure given these different groups varied in relative light intensity (I) from 1 to 2.77 with an approximate contrast γ of from 1.23 to 1.64. The average "exposure density" of these 51 plates was 0.724 and the average contrast γ 1.41. They show a most probable deviation from the mean density for any point on a plate of ± 1.70 percent of which an average value of ± 0.3 percent can be ascribed to variation in the structure of the emulsion and the remainder ± 1.4 percent to the uneven development of the plates. The greatest deviation found for any one of these plates was ± 6.8 percent and it should be noted that two points on this plate might differ in density by 13.6 percent. The average deviation from the mean background density, relative to the average "exposure density" of 0.724, was ± 0.69 percent of which about ± 0.3 percent may be

GROUP DATA		EXPOSURE DATA			DEVELOPMENT DATA				CONTRAST AND DENSITY GROUP AVERAGE					DENSITY RATIOS GROUP AVERAGE			VARIATIONS IN DENSITY				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
GROUP	NO. OF PLATES IN GROUP	EMULSION NUMBER	ADDITIONAL PLATE DATA	RELATIVE INTENSITY	DEVELOPER USED	CONSTITUTION OF DEVELOPER	METHOD OF DEVELOPMENT	TIME OF DEVELOPMENT	CONTRAST γ	TOTAL DENSITY D	EXPOSURE DENSITY Δ	B'GROUND DENSITY D_g	B'GROUND DENSITY FOR D_e	$\frac{\Delta}{D}$	$\frac{D_g}{\Delta}$	$\frac{D_{g'}}{\Delta}$	% A.D. EXPOSURE DENSITY	% A.D. B'GROUND DENSITY	MAXIMUM DEVIATION FROM MEAN DENSITY: GROUP AVE.	GROUP MAX.	GROUP MIN.
a	5	A024	U.Bₘ	1	R	1:20	B	5	1.36	.685	.568	.117	.05	82.6	20.5	9	*1.6	*.8	*3.1	*4.7	*1.5
a'	6	"	"	1	R	1:20	B	5	1.37	.718	.567	.149	.08	79.4	26.3	11	1.6	.6	3.5	4.0	2.6
b	5	"	"	1	PQ 100	1:1	B	5	1.48	.750	.585	.165	.12	75.3	32.6	21	1.9	.7	4.0	4.4	2.5
c	5	"	"	1	R	1:20	BT	5	1.47	.748	.607	.139	.07	81.4	23.0	10	1.4	1.0	3.0	4.9	1.5
d	5	"	"	1	PQ 100	1:1	BT	5	1.46	.761	.545	.216	.15	71.6	39.6	28	2.1	1.0	5.5	7.4	2.9
e	5	"	"	1	R	1:20	T	5	1.29	.680	.554	.105	.04	83.9	19.0	7	1.5	.8	3.4	4.4	2.9
e'	5	"	"	1	R	1:20	T	5	1.43	.719	.591	.129	.06	82.1	21.6	10	1.7	.6	4.3	5.9	5.3
f	5	"	"	1	R	1:100	T	10	1.18	.665	.550	.117	.03	82.3	21.3	9	1.8	.7	4.7	8.7	2.1
g	5	"	"	1	R	1:20 + 1:2 + KBr	T	17	1.64	.777	.658	.118	.05	84.6	18.0	8	1.9	.6	3.0	4.5	2.3
h	5	"	"	1.64	PQ 100	1:1	B	5	1.47_0	1.345	.957	.388	.32	71.1	40.6	33	3.4	.7	7.8	9.5	6.7
h'	5	"	"	1.64	PQ 100	1:1	B	5	1.47_0	1.197	.942	.254	.18	79.3	27.0	19	3.0	1.3	5.1	6.0	4.2
i	4	A141	"	1.38	R	1:20	B	5	1.45	.921	.789	.132	.06	85.7	16.7	8	1.7	.6	2.9	3.4	2.5
j	5	"	Bₘ	1.38	R	1:20	B	5	1.53	.901	.756	.145	.08	83.8	19.2	11	2.3	.7	5.0	6.7	4.6
k	4	"	U.Bₘ	1.38	R	1:20	B-S	5	1.45	.958	.830	.129	.04	86.6	15.5	7	1.7	.6	3.7	5.7	2.6
l	4	"	"	1.38	R	1:20	B-S	5	1.23	.735	.626	.112	.03	84.8	17.8	6	2.0	.7	3.4	4.6	2.3
m	4	"	"	2.77	R	1:20	B-S	5	1.38	1.196	1.076	.118	.05	90.1	8.7	5	1.2	.5	2.4	3.6	1.9
n	4	"	Bₘ	2.77	R	1:20	B-S	6	1.47	1.245	1.098	.147	.08	90.3	13.4	7	2.0	.5	4.3	6.8	2.2

B = BRUSH; T = ROCKED TRAY; BT = BRUSHED, THEN ROCKED; S = PLATES SOAKED; Bₘ = BACKED; U.Bₘ = UNBACKED

(1) ESTIMATED FROM γ FOR D AND d
(2) FOG FREE B'GROUND APRX. .07
(3) AV. DEV. FROM MEAN

FIG. 2. Table of results.

considered due to variations in the plate structure and about ± 0.4 percent to variations in the fog density. In these results the "exposure density" Δ is assumed to be corrected for the density variations of the glass D_g and gelatine constituent of the emulsion D_e by subtracting the adjacent background density from the total density according to Eq. (3), but the variations in density of the glass and gelatine are included in the variations of the background density as part of the variations in the density due to the plate structure. The emulsion variations (caused by the "graininess of materials") occur in both the "exposure density" and the background density but cannot be assumed to be of the same magnitude, so that the average values of the former cannot be assumed to have been corrected by the latter in this respect, as can be seen by comparing curves $A(a)$ and $B(a)$ Fig. 1.

The variations of the "exposure density" for an exposed area $2'' \times 2''$ in the center of the plates average approximately about 50 percent less than those found for an 8×10 plate, but it cannot be assumed that a number of small areas equally exposed corresponding to spectrum lines grouped inside an area $2'' \times 2''$ would develop as evenly as this uniformly exposed area.

In the photographic method, the "exposure density" of the images on the plate is assumed to be proportional to the logarithm of the corresponding light intensities to which the plate was exposed, and in plotting curves showing the relationship between the variations in the light intensity and some variable function of that light intensity (such as the potential across an arc) it is customary to plot the logarithms of these intensities (i.e., values of "exposure densities") instead of using the exponential values of the densities corresponding to these intensities. Unless some method is used for correcting for these variations in density, the percentage errors which will enter into the logarithms of the intensities in the curve should then be approximately the same as the percentage variations in the corresponding densities investigated in this research, for plates having the same emulsion, development and contrast.

The authors have found that one of the best methods for correcting the errors which arise in using the photographic method in the study of spectrum lines is to repeat the exposure to the initial light intensity at regular intervals and move the plateholder of the spectrograph equal distances between all exposures; a correction curve can then be plotted between the densities corresponding to these initial light intensities and the distance between the centers of the line images on the surface of the plate. The density values for other light intensities can then be corrected by this curve according to the position

their images (or spectrum lines) occupy on the plate.

If in addition the exposures are made at equal intervals of time and the times of exposure are the same, a correction is also made by this method for any change in the light source which progresses as some regular function of time, such as may result from the decay in intensity of emission from an oxide coated filament. One of the authors[2] successfully used this latter method in investigating the relationship between the light intensity of the helium spectrum and the potential across the arc in passing through the second ionization potential of helium gas.

The correction curve obtained should be a smooth curve drawn through the density values corresponding to the initial intensities, and will show the variations in densities, for that plate, over the area used for the exposures. When some erratic variations occur, while exposing the plate or in its development, a smooth correction curve cannot be drawn and the plate should be discarded, since it can only lead to false results.

Summary and Conclusion

In this research an attempt has been made to show the general nature of the variations in density over the surface of a plate exposed to light of constant spectral distribution and uniform in intensity to 0.3 percent at all points on the surface of the emulsion, and also to indicate the effect which these variations in density would have on the precision of the photographic method of comparing light intensities. The probable magnitude of these variations of density are calculated and the average percentage variations in the density shown for a large number of plates of the same kind and using several different methods of development. It should be definitely borne in mind, however, that these magnitudes will undoubtedly differ considerably when using other plates, developers, development methods and other spectral distributions in the light to which the plates are exposed.

The magnitude of these variations in density were found to be about the same for "brush" and "rocked tray" development. No marked advantage was found if the plates were soaked an hour before development or if a large quantity of "bromide" were added to the developer. Development fog, however, was found to materially increase these variations in density.

The authors feel that unless some method is adopted to correct for these variations in density from point to point over a plate, the magnitude of which will depend upon the plate used, the precision obtained in the comparison of light intensities by the photographic method will be greatly reduced. A method for making such corrections in the density readings over a plate, which has been successfully used by one of the authors, is described in this paper.

In conclusion the authors wish to express their appreciation of financial aid received from the Faculty Research Committee of the University of Pennsylvania which made possible the completion of this research.

A Note on Photographic Sensitivity after the Herschel Effect

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(Received March 29, 1934)

SIR John Herschel observed that if a photographic emulsion is exposed to white light, and then to light of longer wave-length, the second exposure may partially or wholly destroy the image produced by the first. Claudet[1] announced that during the second exposure a photographic emulsion regains most of its original sensitivity to white light. Volmer and Schaum[2] likewise reported a gain of most of the original sensitivity. More recently Belliot[3] presented data which showed a considerable diminution in sensitivity after these exposures.

A knowledge of the degree to which an emulsion regains its sensitivity under these conditions should aid materially in understanding the nature of the latent image. According to the hypotheses of Blair and Leighton[4] and of Joehnck and Blair,[5] after such treatment the sensitivity should be the same as existed originally. Evidence will be presented in this paper which tends to show that exposure to white light followed by exposure to red light does not affect the sensitivity of the emulsion.

EXPERIMENTAL

Azo number 5 paper is particularly sensitive to the Herschel effect. Sheets of this paper were cut each into three strips. Two strips from each sheet were given different pre-exposures to white light (60 watt Mazda lamp, 110 volts, at 1 meter) for intervals stated in Figs. 1 and 2. The

[1] Claudet, Ann. d. Chim. Phys. **24**, 1848 (3 série).
[2] Volmer and Schaum, Zeits. f. wiss. Phot. **14**, 1 (1914).
[3] Belliot, Comptes Rendus **182**, 1609 (1926).
[4] Blair and Leighton, J. Phys. Chem. **36**, 1649 (1932).
[5] Joehnck and Blair, J. O. S. A. **23**, 67 (1933).

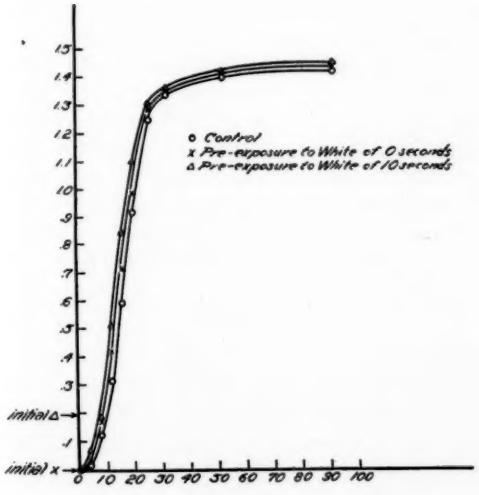
o Control
x Pre-exposure to White of 0 seconds
Δ Pre-exposure to White of 10 seconds
initial Δ
initial x
0 10 20 30 40 50 60 70 80 90 100

FIG. 1.

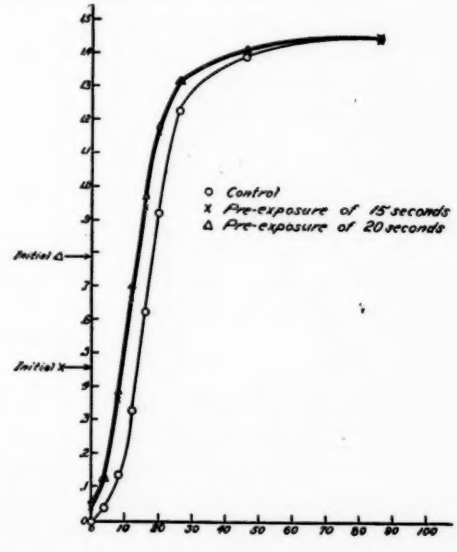

FIG. 2.

FIGS. 1 and 2 showing density (ordinate) plotted against time of exposure to white light in seconds. The circles indicate the values obtained upon ordinary emulsions; the crosses and the deltas those obtained upon emulsions which have been pre-exposed to white light, then bleached with red light, and finally re-exposed to the white light. The arrows along the ordinates indicate the densities produced by the pre-exposures.

developable densities produced by these exposures are shown by the arrows along the ordinates in those figures. The other strip, the control, was not pre-exposed.

All of these strips, except the controls, were next exposed for 437 hours to the radiation from a yellow 25 watt lamp enclosed in a red Massirubin Inactin shell. This radiation was all of wave-length longer than 5400A and much of it was in the infrared. Twenty-seven percent of this radiation was found to be transmitted through 1 mm of hard rubber. The intensity upon the paper was 733 ergs/cm²/sec.

Portions of each sheet, including the controls, were then exposed to white light (100 watt Mazda lamp, 105 volts, at 1 meter) for the various periods indicated by the abscissae of Figs. 1 and 2. They were then developed in an elon-hydrochinon developer (E. K. Co. formula D 72, 1–2) at 21° for 45 seconds, then fixed and dried upon ferrotype plates. The normal reflection densities were measured with a photoelectric densitometer described by Blair, Hylan and Meredith.[6] The curves in the figures show the densities produced by varying exposures to the second white light.

Interpretation

The densities produced upon those strips which had been pre-exposed, bleached, then re-exposed were greater than those produced upon the controls by equal exposures, and the greater the pre-exposure the greater this difference. It is apparent, however, that this difference is due to a residual density from the pre-exposure. If the time of exposure necessary to produce this residual density is added to the abscissae for each of the pre-exposed strips, the curves for the pre-exposed strips and the controls would, within the limits of experimental error, be superimposed. Other data not presented here tended to confirm this. It seems that the original sensitivity is fully regained when this photographic emulsion is exposed to white then to red light, but from these data we cannot safely generalize for all photographic emulsions.

[6] Blair, Hylan and Meredith, Phot. J. 73, 409 (1933).

Secondary Interference Fringes

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(Received April 13, 1934)

A dissonance phenomenon is observed to occur between two types of interference fringes: (1) those produced by stationary light waves formed in front of a mirror and made visible on a thin translucent film and (2) the fringes of equal thickness formed by the wedge of air enclosed between the thin film and the mirror.

INTRODUCTION

STATIONARY light waves have been observed by various methods: originally by Wiener,[1] photographically; by Drude and Nernst,[1] with a fluorescent film; by Selenyi,[1] with a thin translucent film[2] of sulphur; and by Ives and Fry,[3] using a photoelectric method. In all arrangements the stationary waves, planes of nodes and loops, are produced in front of a totally reflecting mirror surface by allowing (monochromatic) light to fall upon the surface and be reflected back upon itself. The planes of nodes and loops are then detected by means of a very thin film, usually on glass, placed so as to intercept them at an oblique angle. By the wedge of air thus formed are produced also the usual interference "fringes of equal thickness." Selenyi explains clearly how these fringes will be produced together with the stationary waves and ingeniously devises a method of observing the latter only. With the arrangement to be described both sets of fringes are observed together and the "beats" or dissonance between them is considered quantitatively in a simple special case.

METHOD

The most satisfactory thin film is easily prepared on a clear flat glass plate as follows: a few drops each of hydrochloric acid and ammonia water are placed apart on a glass table, the glass plate is placed on the table near the liquid drops, and the whole covered by a glass dish. By a few turns of the table a uniform film of ammonium chloride is deposited on the plate. The plate is then removed and a dilute collodion solution, 1 : 300, is flowed over it and allowed to dry. Next the film is polished with a soft pad of absorbent cotton. Such a film should have a thickness of about 1/20 of a wave-length of visible light, and the light transmission of it with the glass plate should be about 85 percent.

A plane glass surface, silvered; or, better, a stainless steel mirror is illuminated at perpendicular incidence by a sodium flame or mercury vapor lamp. The source of light should subtend a small angle, 5 degrees say, at the mirror.

The film side of the glass plate is laid on the mirror; so as to form a thin wedge of air between itself and the mirror. With the angle of observation about 30 degrees, and the thin end of the air wedge toward the observer, a pattern is seen as in the accompanying photograph. The photograph is enlarged 4 times (only on account of the small size of the mirror used), and the right half is retouched to bring back the original sharpness of the small fringes.

RESULTS

As stationary light waves are formed above the mirror they are intersected by the thin film and if viewed along the normal to the mirror appear a distance d apart depending on the angle between the film and the mirror. Likewise fringes of equal thickness are formed by the wedge of air and for similar reasons of interference appear, viewed along the normal, a distance d apart. Also, both

[1] See Wood's *Optics*, 3rd Ed., p. 210 ff.

[2] The word "film" is used here and below. Strictly speaking, the "film" is a "layer of small particles."

[3] Ives and Fry, J. Opt. Soc. Am. **23**, 73 (1933).

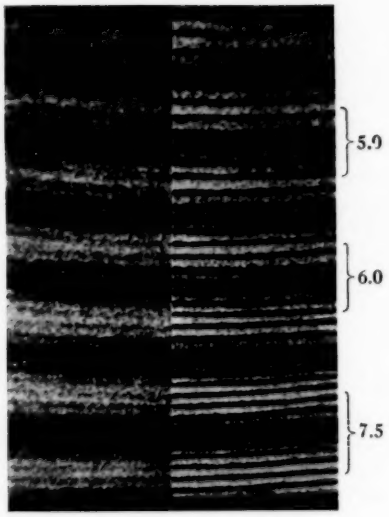

FIG. 1. Large fringes result from dissonance of two sets of smaller fringes, angle of observation about 30° near bottom of photograph. Towards the top as angle increases beats are more frequent. Right side of photograph is retouched.

sets of fringes under this condition are formed *at the air wedge* in coincidence. No dissonance is apparent. But when viewed at an angle of 30 degrees the fringes caused by stationary waves on the film *at the wedge* appear $d \cos 30°$ apart; whereas the fringes of equal thickness are formed *above the wedge* with the apparent separation of $d \cos 30°/\cos 30°$ or d. The locations of these fringes can be found with a low power microscope and their widths measured for any angle.

Dissonance or consonance should occur, observing at 30 degrees, every $d/(d-d \cos 30°)=7.5$ stationary wave fringes. This can be seen in the lower portion of the photograph (Fig. 1). It is difficult to say definitely whether the small fringes there are due to stationary waves or are fringes of equal thickness, in which case there would be 6.5 in each "beat," as in the center of the photograph. This might have been determined by photographing them under diffuse light when no stationary waves appear, consequently no beats. The fringes at the top of the photograph were seen by the camera at an angle several degrees larger than 30 degrees, therefore there are fewer small fringes between the beats.

For angles of the incident light other than zero phenomena of the same type are, of course, observed. Questions of the state of polarization of the incident and reflected light are answered by Selenyi,[4] and discussed also by Wood.

Even with white light as the source of illumination a few colored beat fringes are observed indicating the presence of stationary waves although the smaller fringes themselves are not visible.

[4] Selenyi, Ann. d. Physik **35**, 444 (1911).

Proceedings of the New York Meeting of the Optical Society of America

FEBRUARY 23–24, 1934

JOINT MEETING WITH AMERICAN PHYSICAL SOCIETY

The joint meeting of the Optical Society of America and the American Physical Society was held in New York City, February 23–24, 1934.

JOINT SYMPOSIUM ON MEASURING SPECTRAL RADIATION

The principal feature of the meeting was the joint symposium of the two societies on Friday morning, February 23, devoted to invited papers on *Measuring Spectral Radiation*. The following papers were presented:

1. **Fundamental Principles.** W. E. FORSYTHE, *General Electric Company.*
2. **Methods of Obtaining Spectral Radiation.** HENRY KURTZ, *Bausch & Lomb Optical Company.*
3. **Measuring Energy with Blackened Receivers.** C. G. ABBOT, *Smithsonian Institution.*
4. **Measuring Energy with Photographic Plate.** BRIAN O'BRIEN, *University of Rochester.*
5. **Measuring Energy with Photoelectric Tube.** L. R. KOLLER, *Bureau of Standards.*
6. **Visual Measurements (Spectrophotometry).** K. S. GIBSON. *Bureau of Standards.*

The following invited papers on the same subject were presented before the Optical Society Friday afternoon:

7. **Sources of Radiation.** A. G. WORTHING, *University of Pittsburgh.*
8. **Analysis of Radiation by Gratings.** R. C. GIBBS, *Cornell University.*
9. **Optical Features of the Spectrometer.** B. T. BARNES, *General Electric Company.*
10. **Slit Width Corrections.** W. W. WENIGER, *Oregon State College.*
11. **Methods of Blackening Receivers and Amplification of Galvanometer Reflections.** A. H. PFUND, *The Johns Hopkins University.*
12. **Radiometers and Radiomicrometers.** B. J. SPENCE, *Northwestern University.*
13. **Ultraviolet Spectrometer and Densitometer.** G. R. HARRISON, *Massachusetts Institute of Technology.*

JOINT DINNER

President Arthur H. Compton of the Physical Society presided at the joint dinner Friday evening.

SIMULTANEOUS SESSIONS

Simultaneous sessions of the American Physical Society and the Optical Society of America were held Friday afternoon and Saturday morning and afternoon.

CONTRIBUTED PAPERS

The sessions of the Optical Society Saturday morning and afternoon were held for the reading of contributed papers. The authors' abstracts of these papers are appended.

MEETING OF THE BOARD OF DIRECTORS

A meeting of the Board of Directors was held Thursday afternoon and evening, February 22. Minutes of this meeting are appended.

L. B. TUCKERMAN, *Secretary*

Minutes of the Third Meeting of the Directors of the Optical Society of America, Incorporated

NEW YORK, NEW YORK, FEBRUARY 22, 1934

Besides the transaction of routine business, the following items of general interest to members of the Society were taken up:

The following results of letter ballots were reported:

Appointments

Members of Finance Committee:

Henry F. Kurtz, *Chairman*	Edgar D. Tillyer
C. L. Bausch	J. P. C. Southall
L. A. Jones	T. R. Wilkins
F. K. Richtmyer	

Auditors of the Treasurer's Accounts:

Carl L. Bausch
C. W. Frederick

Auditors of the Journal Accounts:

G. E. Grantham
F. R. Hirsh

Associate Editors of the Journal, for six year term beginning January 1, 1934:

Saul Dushman	P. E. Klopsteg
K. S. Gibson	W. B. Rayton
L. O. Grondahl	H. B. Williams

Members of Committee on Meetings and Programs:

Brian O'Brien, *Chairman*	Gordon H. Gliddon
J. W. Beams	W. E. Forsythe

Nomination

Member of Governing Board of the American Institute of Physics:

E. C. Crittenden, for the term beginning February, 1934 and expiring February, 1937.

Compensation of Editor of Journal

The following resolution was unanimously adopted:

"The Editor of the Journal of the Optical Society shall receive from the Society $500.00 per annum in compensation for his personal services in this capacity."

The following appointments by the President were approved by the Directors:

Members of Membership Committee for the term of 1933–35:

H. W. Farwell, *Chairman*	E. O. Lawrence
Frank Benford	M. Rea Paul
I. C. Gardner	E. P. T. Tyndall
L. Gilchrist	J. B. Nathanson
Geo. R. Harrison	Joseph Razek
H. E. Howe	Wm. Herriott
S. Jacobsohn	R. A. Porter
R. Kingslake	Harlan T. Stetson

Members of Colorimetry Committee for the term of 1933–35:

L. A. Jones, *Chairman*	A. E. O. Munsell
E. Q. Adams	Dorothy Nickerson
Chas. Bittinger	M. R. Paul
H. P. Gage	J. W. Forrest
K. S. Gibson	C. E. Foss
A. C. Hardy	E. C. Crittenden
D. B. Judd	Carl Z. Draves
E. M. Lowry	I. H. Godlove
	Louise L. Sloan

Members of the Committee on Transfer for 1933–35:

L. B. Tuckerman, *Chairman*	L. O. Grondahl
R. T. Birge	G. W. Moffitt
A. C. Hardy	G. S. Monk
Henry Crew	Edison Pettit
K. K. Darrow	A. H. Pfund
W. E. Forsythe	Brian O'Brien
J. S. Friedenwald	

The following representatives were elected:

On the Division of Physical Sciences National Research Council:

D. L. Webster, term to expire June 30, 1937.

On the Council of American Association for Advancement of Science:

P. I. Wold, term to expire February, 1935.
W. E. Forsythe, term to expire February, 1936.

On the American National Committee on International Congresses on Photography:

A. C. Hardy, term to expire October, 1935.

On the U. S. National Committee of the International Commission on Illumination:

Frank Benford, term to expire November, 1935.

Treasurer's Report

The Treasurer's report showed a net increase in the funds of the Society of $542.58 instead of the budgeted loss of $175.00 or the loss of $46.31 estimated in October. This included an unbudgeted contribution of $500.00 from the Eastman Kodak Company, but even if that were not counted there was a gain of $42.58 instead of the estimated loss.

Final disposition of balance of funds of the J.O.S.A. and R.S.I.

The Editor reported that, with the approval of the Scientific Apparatus Makers of America, the balance of these funds had been equally divided between the Optical Society of America and the American Institute of Physics.

Amendments to the By-Laws:

The By-Laws were amended as follows:

Art. II, Section 7, to read:

"*Voting:* Upon any question with respect to which a vote of the membership shall be required or deemed advisable, the board of directors may determine whether such vote shall be taken by mail or by ballot at the next meeting of the membership. In case the directors shall determine to take such vote by mail, either upon any question of administration or policy or upon the election of officers, directors or others, forms for the casting of such vote or for the casting of a ballot for the election of any such officers, directors, or others, shall be forwarded to the entire membership entitled to vote thereon at least thirty (30) days prior to the date upon which the count of such votes or ballots shall be made by the directors or tellers appointed for the purpose (the date of which count shall be incorporated in the advice sent to the respective members) and the result of such vote or ballot shall be determined by the directors or tellers upon the date fixed for such purpose and shall be valid, binding and of full force and effect precisely as if such vote had been taken in open meeting of the membership regularly called and duly held, provided always, that in order to render valid such vote by mail, the number of votes cast shall be at least equal to the number of voting members required to constitute a quorum at any regular or special meeting of the membership."

Art. III, Section 5, to read:

"*Time of Election and Assumption of Duties:* Election by the members of officers and members at large of the board of directors shall take place at an annual meeting of members in October, or by mailed ballot as provided in the following section.

"The officers and directors elected shall assume their duties at the close of such annual meeting."

Art. IV, Section 1, to read:

"*Committees:* The President may appoint, for a term not to exceed the remainder of his term of office and subject to the approval of the board of directors, such committees as may further the objects of the Society, and such committees shall have such duties and responsibilities as shall be delegated to them by the President and the board of directors, but shall be subject at all times to the direction and control of the board of directors. Unless otherwise specifically provided in its appointment, each such committee shall serve until it has been discharged or its successor has been appointed."

Art. IV, Section 2, to read:

"*Representatives and Delegates:* The President shall submit to the board of directors nominations for representatives and delegates to other organizations. Representatives and delegates shall be elected by the board of directors and for such terms as their respective offices may require. Unless otherwise specifically provided in his appointment each such representative or delegate shall serve until he has been discharged or his successor has been appointed."

The effect of these amendments was:

1. To make possible the official count of the ballots in advance of the annual meeting so that officers elected can be notified of their election in advance.

2. To make it unnecessary for the incoming president to reorganize all the committees immediately upon taking office unless he should so desire.

Memorial to Adolph Lomb:

The following resolution was adopted:

"*Whereas,* Mr. Adolph Lomb was largely instrumental in promoting the organization of the Optical Society of America and gave enthusiastically of his time and energy to its affairs and during his lifetime made generous donations to the Society, and

Whereas, in accordance with his specific request, the Optical Society of America has received from the executors of his estate the sum of five hundred dollars ($500.00), be it therefore

Resolved: That the said sum of five hundred dollars ($500.00) be kept in a separate fund, to be known as the Adolph Lomb Memorial Fund, and to be used for purposes hereinafter set forth; and

Resolved Further: That the Society at this time appropriate the sum of one thousand five hundred dollars ($1,500.00) from the current funds of the Society to be paid into and to augment the Adolph Lomb Memorial Fund; and

Resolved Further: That the Treasurer be hereby instructed to invest the moneys of such Fund, namely, two thousand dollars ($2,000.00), and such additional amounts as may be added to the Fund from time to time, in securities under the same conditions and subject to the same regulations in respect to maintenance, change in investment and control, as the other invested funds of the Optical Society of America; and

Resolved Further: That the income of this fund be expended, in the discretion of the board of directors, for purposes in keeping with the objects of the Society and appropriate as memorials, such as the establishment of a memorial lectureship; awards for distinguished service to the Optical Society of America; awards for outstanding contributions to optical science; and the like."

Thanks to Charles Bittinger:

The Directors voted that the Secretary be instructed to send a letter of thanks to Charles Bittinger for his work in designing the new cover of the Journal for 1934.

L. B. TUCKERMAN, *Secretary*

Program of Sessions for Contributed Papers

(TITLES AND ABSTRACTS* OF PAPERS)

14. An Eyepiece for Measuring the Amount of Plane Polarization in a Beam of Light. FRED. E. WRIGHT, *Geophysical Laboratory, Carnegie Institution of Washington.*

With this eyepiece the plane polarization in a beam of light is compensated by means of a plane-parallel plate of glass or of celluloid tilted at the proper angle. The test, to ascertain if the compensation is complete, is made by means of a biquartz plate and a second tiltable plate in combination with a Savart plate and nicol or Wollaston prism. The biquartz plate is 1.76 mm thick and consists of two plates of quartz cut normal to the optic axis, the one of dextrogyre, and the second of levogyre quartz, mounted side by side with a vertical junction face. For mercury green light of wave-length 5461A, the rotation is ±45°. An incident, plane polarized beam is divided into two beams such that the plane of vibration of the one in the first half of the biquartz plate is normal to that of the other beam in the second half. The second plane-parallel, tiltable plate is mounted above the biquartz plate with its axis of rotation in the plane of vibration of the wave emerging from one of the biquartz plate halves. By means of this tiltable plate a small amount of polarization may be added to, or subtracted from, the polarization in the transmitted beams. This second tiltable plate was first used by B. Lyot in his analysis of the light from the moon and the planets. The Savart plate and analyzing prism are employed to detect the presence of polarized light in the beam. During the past year the eyepiece has been used chiefly in the measurement of the percentage polarization of light reflected by different parts of the moon's surface and by terrestrial materials. It has also been employed for the measurement of sky polarization and in metallographic work. It serves well both for monochromatic and for natural light. With it the amount of plane polarization can be determined, for low percentages, to one-tenth of one percent.

The present paper will appear in full in Journal Optical Society of America.

* The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts here reprinted.

15. A New Recording Color Analyzer. ARTHUR C. HARDY, *Massachusetts Institute of Technology.*

A recording photoelectric spectrophotometer employing the null method was described in a previous communication.[1] The new instrument, which has been in constant use for more than a year, utilizes the same basic principles with an improved optical system. The present system consists of a double monochromator, which is followed by a photometer unit consisting of two Rochon prisms and a Wollaston prism. The Wollaston prism separates the beam leaving the monochromator into two beams, one of which falls on the sample and the other on the standard. The Rochon prism behind the Wollaston prism is rotated at high speed to produce the alternation of the two beams required by the null method. The Rochon prism ahead of the Wollaston prism is used like the nicol in a Martens photometer to control the relative intensity of the two beams. Since both beams traverse the same optical parts, the effect of selective absorption or selective reflection is completely eliminated. Due to the employment of the null method, the readings are not affected by variations in the light source, the photoelectric cell, or the associated amplifier.

[1] J.O.S.A. and R.S.I. **18**, 96 (1929).

16. A Photoelectric Colorimeter and Its Application to Grading Rosin. BROOKS A. BRICE, *Food and Drug Administration, U. S. Department of Agriculture.*

A null method photoelectric colorimeter possessing the advantages of low cost, portability, ease and rapidity of operation, high precision, and direct reading of percent transmission, has been developed for grading rosin and is applicable to other color problems.

It consists essentially of a lamp, pairs of color filters, two Weston Photronic cells connected in opposing parallel, a galvanometer, a rheostat potentiometer equipped with a dial reading from 0 to 100, and a compensating resistance which makes the dial read percent transmission directly. The value of the compensating resistance depends on the

characteristics of the photo-cells and on the magnitude of the currents and resistances in the circuit, and was found experimentally by obtaining dial readings on a set of wire screens of known transmissions. It is apparently possible, by proper selection of photo-cells and resistances, to make the accuracy of the dial readings equal to the accuracy of the known screen transmissions. The reproducibility of readings is about 0.2 division of the dial scale.

Visually, the grade of a rosin sample is decided by comparing its color (chromaticity and brightness) with that of a glass color standard, brightness being involved because of the presence of fine dirt in commercial gum rosin. Disagreements even between experienced observers are frequent. With the photoelectric apparatus, the green transmission G and the red transmission R of the rosin sample are measured by balancing the circuit using blue-green and red filters. The ratio G/R is taken as a measure of the chromaticity of the sample, and a tentative empirical relation $G/(R+10)$ gives a color index which weighs brightness with chromaticity in good agreement with best accepted visual grading.

17. Standardization of Lovibond Red Glasses. K. S. GIBSON AND GERALDINE K. WALKER, *Bureau of Standards.*

The method of standardization of the Bureau's Lovibond red glasses was briefly indicated in a previous abstract.[1] Over 2000 red glasses have now been calibrated in terms of the Priest-Gibson (N″) scale and unit which were established in 1927. Results on the first 1000 glasses[2] will be illustrated.

Further study of the N″ scale has been made, including extensive comparisons of values of N″ derived both from spectral transmission and from direct comparison with the Bureau's standard glasses. The additive and consistent nature of the N″ scale has been confirmed by this study.

The present paper will appear in full in Bur. Standards J. Research.

[1] Irwin G. Priest and K. S. Gibson, *Standardising the Red and Yellow Lovibond Glasses*, J.O.S.A. and R.S.I. **16**, 116 (1928).

[2] Geraldine K. Walker, *Statistical Investigation of the Uniformity of Grades of 1000 Lovibond Red Glasses*, Bur. Standards J. Research **12**, March, 1934.

18. The Basis for Wave-Length Discrimination by the Color-Blind. SELIG HECHT AND SIMON SHLAER, *Columbia University.*

Measurements with two deuteranopes and one protanope show that, when brightness differences are eliminated, wave-length discrimination is practically absent at both ends of the spectrum, and exists only in a band between 470 and 570 mμ. Both edges of this discrimination band are fairly sharp; the short wave edge is at 470 for all three observers; the long wave edge varies between 550 and 570 at different times for the different observers.

The distance in wave-length which must separate two wave-lengths for them to be recognized as different when brightness differences are eliminated is a minimum at the neutral point, and increases exponentially with the distance from the neutral point. The function is not symmetrical about the neutral point, because the values on the long wave side rise more slowly than on the short wave side.

The basis on which the color blind discriminates wave-length on each side of the neutral point is relative saturation. The short wave stretch of the spectrum up to the neutral point is matched by mixtures of 440 mμ and white of color temperature 5000°K. Similarly the stretch between the neutral point and 700 mμ is matched by mixtures of white and 650 mμ. For example, to match 490 mμ the protanope whose neutral point is 491.5, requires a brightness ratio (measured by himself) of white to 440 mμ of nearly 1000; for 485 it drops sharply to 100; for 480 it is 10; and for 475 it is 1. Similarly to match 492 the brightness ratio of white to 650 mμ is about 150; for 495 it drops to 1; for 510 to 0.1; and for 570 to 0.01. To the color-blind the spectrum is thus two hues which increase in saturation from the neutral point outwards.

In view of the wave-length discrimination of color-blinds, their previously recorded color mixture equations cannot be considered unique except near the neutral point. Elsewhere the equations are in part determined by the relative brightness of the measuring primaries. Our measurements confirm this conclusion.

The present paper will appear in full in The Journal of General Physiology.

19. A Maxwell Triangle Yielding Uniform Chromaticity Scales. DEANE B. JUDD, *Bureau of Standards.*

The length of a line on the Maxwell triangle of the I.C.I. coordinate system for colorimetry[1] is an approximate index of the chromaticity difference between the stimuli represented at the extremes of the line; the O.S.A. coordinate system also has this property, and to about the same degree of approximation.[2] However, sufficient data on chromaticity sensibility have now been gathered to show that the Maxwell triangle of both systems can be improved upon in this respect. It has been found possible to effect very marked improvement, so much so that the new coordinate system has been called the "uniform-scale system" because it is so closely true that uniform chromaticity scales may be derived from it merely by stepping off equal intervals on the Maxwell triangle. The agreement of scales so derived with extant data on chromaticity sensibility will be shown graphically. This includes sensibility to wave-length change in the spectrum and at colorimetric purities less than one, sensibility to purity change for various purities and dominant wave-lengths, and sensibility to color-temperature change.

An important application of this coordinate system is its use in finding from any series of chromas the one most resembling any other given chroma, for example, the finding of the nearest color temperature for any non-Planckian stimulus.[3] The method, of course, is to draw the shortest line from the point representing the non-Planckian stimulus to the Planckian locus.

It should be noted that the coordinate system derived is not the only one which will yield a uniform-scale triangle. The area representing real stimuli may be uniformly

[1] Judd, *The 1931 I.C.I. Standard Observer and Coordinate System for Colorimetry*, J.O.S.A. **23**, 359 (1933).

[2] Judd, *Chromaticity Sensibility to Stimulus Differences*, J.O.S.A. **22**, 72 (1932).

[3] Davis, *A Correlated Color Temperature for Illuminants*, Bur. Standards J. Research **7**, 659 (1931).

expanded or contracted, moved about the triangle, or reoriented without injuring the agreement with sensibility data. On this account, there is promise that it can be incorporated into many of the theories of vision such as that of Hering, or the Hecht development of the Young-Helmholtz theory, or the zone theory of G. E. Müller.

20. The Scattering of Infrared Radiations by Small Particles. A. H. PFUND, *Johns Hopkins University.*

The scattering by transparent particles is inferred from transmission measurements. Experiments on transmission were carried out in the infrared since here the wave-length may be made large in comparison with particle-size (Rayleigh condition for scattering). Zinc-oxide pigments of known particle-size, ranging in diameter from 0.09 to 0.4 microns and completely dispersed in rubber and xylene, were studied in the spectral region 0.5 to 2.7μ. Dry pigment films could be investigated to 7μ and beyond. Following are the results:

1. The transition from non-selective reflection to scattering sets in when the wave-length is about equal to the particle-diameter.

2. Rayleigh's inverse fourth-power law was verified for the rubber dispersion of zinc-oxide (0.09 micron diameter) over the spectral range 0.8 to 2.4μ.

3. By taking known mixtures of particles having diameters of 0.09 and 0.4 micron, respectively, transmission curves were obtained. These led to the conclusion that a statement of the average particle diameter is insufficient to define the pigment uniquely.—However, by imposing the two conditions (1) that the average diameter have a definite value, (2) that the transmission curve be of definite form, a closer approach to specification of the pigment is realized. For this work it is necessary that the transmission curves be obtained in a spectral range within which the wave-lengths are too small to enable Rayleigh's law to apply.

4. By proceeding to a region of greater wave-length where Rayleigh's law holds, it becomes theoretically possible to evaluate the refractive index of particles which are below the limit of resolution of the microscope.

The present paper will appear in full in Journal of Optical Society.

21. Luminescence of Thorium Oxide Activated by Rare Earths. Optimum Concentration for Different Sources of Excitation. FRANCES G. WICK AND CHARLOTTE G. THROOP, *Vassar College.*

Thorium oxide containing a small amount of a rare earth is luminescent under different sources of excitation, the intensity of luminescence varying with the concentration of the rare earth. Three sets of specimens were prepared containing as activators praseodymium, samarium and terbium in concentrations varying by known amounts and including such as were above and below that that required for optimum brightness. Identical methods of preparation and subsequent heat treatment were used for the different specimens. The only difference in the specimens of a group was that of concentration of the rare earth. The concentrations of praseodymium used varied from 1 atom of praseodymium to 100 molecules of thorium oxide to 1 atom to 100,000 molecules; those of samarium from 1 atom in 15.5 molecules to 1 atom in 2000 molecules; those of terbium from 1 atom in 10 molecules to 1 atom in 40,000 molecules.

By means of an optical pyrometer the intensity of fluorescence each of the specimens of varying concentration of a rare earth was measured when the source of excitation was cathode rays, when it was ultraviolet light and when it was the hydrogen flame. From these observations the concentration of rare earth required for maximum intensity under each of these sources—the "optimum concentration"—was determined. The "optimum" is widely different when different sources of excitation are used.

The results of the observations upon thorium oxide with the three different rare earths as activators are shown in the following table which gives the concentrations required for most intense excitation—the "optimum concentration."

	Source of Excitation (Molecules of ThO_2 per atom)		
Activator	Cathode rays	Hydrogen flame	Ultraviolet
Terbium	389	158.5	69.18
Samarium	69.18	23.44	48.98
Praseodymium	489.8	263.	346.7